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(54) **ALUMINUM ALLOY**

(57)Abstract:
PROBLEM TO BE SOLVED: To obtain an aluminum alloy having a specific Charpy impact value, excellent in formability and workability, and suitable for use in production on an industrial scale by incorporating Fe, Cr, and Ni and specifying a composition and a structure, respectively.
SOLUTION: This alloy is an Al alloy which contains, by weight, 2-7% Fe, 2-12% Cr, and 1-10% Ni (where $7 \leq Fe+Cr+Ni \leq 15$ is satisfied) and in which at least a part of alloy structure is composed of quasi-crystal and Charpy impact value is regulated to ≥ 2 J/cm2. Further, 0.01-2.5% of Zr can be incorporated into this alloy (where $7 \leq Fe+Cr+Ni+Zr \leq 15$ is satisfied). Fe is an essential component for constituting a quasi-crystal formed mainly in the alloy, and Fe atoms which do not constitute quasi-crystals form Al_3Fe, etc., and these contribute to the improvement of heat resistance, etc.; however, incorporation of Fe in an amount exceeding 7% causes deterioration in toughness and ductility. Although Cr makes the same contribution as Fe does, its incorporation in an amount exceeding 12% causes deterioration in ductility. Ni contributes to the improvement, e.g. of the strengthening and stabilization of quasi-crystals, but the possibility of causing deterioration in toughness and ductility is brought about when Ni content exceeds 10%.

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] This invention relates to an aluminum alloy.
[0002]
[Description of the Prior Art] An aluminum alloy has the characteristic outstanding in lightweight nature, thermal conductivity, specific strength, etc., and is broadly used for an airplane, a car, and a motorcycle and other machine parts. In particular, in recent years, many of aluminum alloys which were excellent in heat resistance with high intensity, or its composite material are developed.
[0003] However, not only cold work nature but hot-working nature is dramatically bad, and cannot fabricate such materials with the existing extrusion machine, a forging machine, etc. in many cases. Even if it is able to fabricate, it will be difficult to avoid defects, such as a crack and BIBIRI. Even if it is fabricated healthfully and these defects do not exist, the toughness in the room temperature of mold goods itself will be insufficient. For this reason, it is very difficult to add cold work to the obtained mold goods further.
[0004] Although the amorphous (amorphous) alloy by composite, the mechanical alloying method, rapid quenching, etc. which made the aluminium powder distribute a whisker, ceramics particles, etc., the compound between aluminum basic metal, etc. are developed as high intensity and a heat-resistant aluminum alloy about this, It is hard to say that the alloy by these art also fits production on an industrial scale from the complexity of a manufacturing process besides the problem shown above, the height of a manufacturing cost, etc.
[0005] The whisker etc. which serve as the distributed material in the composite which makes the above-mentioned whisker etc. dispersion-strengthening material are expensive, and the process to distribute also takes time and effort and, specifically, moreover, the evaluation is not easy, either. The more it strengthens, it will become scarce and, the more a moldability will also fall to ******.
[0006] In the mechanical alloying method, since a little powder must be processed within a ball mill for a long time, productivity is remarkably low, and as a result of taking up oxygen etc. during processing, ****** falls gradually. And many rearrangements have existed and work hardened to the powder obtained.
It becomes a cause by which this bars a moldability.
[0007] The high pressure gas used for the device for quenching and it in the amorphous after alloy powder by rapid quenching is expensive. Rare metals, such as yttrium expensive as an amorphous formation element and cerium, are also required. Below with crystallization temperature, since it is hard to change, the after alloy powder obtained cannot be fabricated easily.
[0008] On the other hand, although there is also a method indicated by JP,3-267355,A as art of using AMORUFASU, since the content beyond Cr:17.6 % of the weight is needed, a ductile fall is not avoided. There are many points which should be improved in addition, such as a problem of the moldability below complicated processing of the weight increment by Cr, amorphous-izing, etc. and crystallization temperature.
[0009]
[Problem(s) to be Solved by the Invention] Therefore, especially this invention primarily aims to provide the aluminum alloy which was excellent in a moldability and processability, and fitted production on an industrial scale.
[0010]
[Means for Solving the Problem] As a result of repeating research wholeheartedly in view of a

problem of these conventional technologies, this invention person finds out that an aluminum alloy which has a specific presentation and structure can attain the above-mentioned purpose, and came to complete this invention.

[0011] This invention is aluminum an alloy used as a base, and namely, (1) Fe:2-7 % of the weight, Cr: 2-12 % of the weight and nickel : 1 to 10 % of the weight (however, 7 % of the weight ≤Fe+Cr+nickel≤15 % of the weight) is contained, (2) At least a part of alloy structure is a quasicrystal, and start an aluminum alloy, wherein (3) Charpy impact values are more than 2 J/cm^2.

[0012]

[Embodiment of the Invention] Hereafter, this invention is explained with the embodiment.

[0013] First, each ingredient in this invention aluminum alloy is explained. However, since each ingredient of this invention aluminum alloy is what acts each other, it explains discussing the reason for limitation of each ingredient individually as a reason that it is not necessarily suitable and general.

[0014] Since the quasicrystals (quasicrystal of an aluminum-Cr-Fe (for example, aluminum$_{80}$Cr$_{13.5}$Fe$_{6.5}$) system, etc.) formed mainly in this invention aluminum alloy are constituted, Fe is an indispensable ingredient, and it may usually be 2.5 to 5 % of the weight preferably about 2 to 7% of the weight. The Fe atoms which do not constitute a quasicrystal form aluminum$_3$Fe, aluminum$_9$FeNi, etc., and these contribute to heat-resistant improvement. However, if the above-mentioned content exceeds 7 % of the weight, it will be easy to make aluminum$_3$Fe, aluminum$_9$FeNi, etc. big and rough, and there is a possibility of causing the fall of ******.

[0015] Cr is an ingredient required since the quasicrystal phase in this invention aluminum alloy is constituted mainly like Fe, and is just usually 3 to 6 % of the weight preferably about 2 to 12% of the weight. If the above-mentioned content exceeds 12 % of the weight, ductility will fall, and there is a possibility that elongation after fracture may almost be lost. The Cr atom which does not constitute a quasicrystal is contributed to heat-resistant improvement, as a result of forming aluminum$_{13}$Cr$_2$ etc.

[0016] Nickel is replaced-type-dissolving mainly to the quasicrystal of the above-mentioned aluminum$_{80}$Cr$_{13.5}$Fe$_{6.5}$ system, etc., and is contributed to the improvement in strengthening of a quasicrystal, stability, etc. The content is just usually 2 to 6 % of the weight preferably about 1 to 10% of the weight. The Ni atoms which do not constitute a quasicrystal form eutectic structure with compounds, such as aluminum$_3$nickel and aluminum$_9$FeNi, or aluminum, etc., for example. When a Ni content exceeds 10 % of the weight, it becomes easy to make the above-mentioned compound etc. big and rough, and there is a possibility that ****** may fall.

[0017] The mode which contains Zr further is also included in this invention aluminum alloy. Within the limits of a constant rate, Zr dissolves in aluminum matrix and can be contributed to solid solution strengthening. Since Zr in aluminum has the low diffusion coefficient, the dissolution state is comparatively stable also at an elevated temperature. From this standpoint, Zr content is just usually 0.1 to 1 % of the weight preferably about 0.01 to 2.5% of the weight. In this way, even if it is little compared with other ingredients, Zr is effective also in the minuteness making of an organization. When Zr content exceeds 2.5 % of the weight, compounds, such as aluminum$_3$Zr, crystallize and there is a possibility that ****** may fall. And there is a possibility that the melting point of an alloy may become high in this case, and the viscosity of a molten metal may become high.

[0018] In this invention aluminum alloy, besides the above-mentioned element, at least one sort, such as Mg, Si, Cu, Mn, V, Ti, and Mo, can also be added if needed by 0.01 to 3% of the weight of within the limits, respectively in order to raise room temperature strength, high temperature strength, etc.

[0019] When these additions exceed 3 % of the weight, there is a possibility that the problem which changes with each elements as follows may arise. A big and rough compound is produced and, in the case of V, Ti, Mo, and Mn, there is a possibility that ductility may fall remarkably. In the case of Si, it especially crystallizes or deposits independently, and there is a possibility that fracture toughness may fall. In the case of Mg and Cu, while there is work which is an element contributed to the intensity from a room temperature to near 200 **, and improves hot-working nature, Cu tends to produce Fe, aluminum, etc. and a compound, and the probability that Mg will form an oxide becomes high. As for especially the sum total addition of elements, such as these Mg, it is preferred to consider it as 0.01 to 3 % of the weight 5 or less % of the weight from a viewpoint of a moldability and toughness.
[0020] In this invention, even if contained within limits which do not spoil the effect of this invention even if it is other ingredients other than the above-mentioned ingredient, it does not interfere.
[0021] At least a part of the organization is constituted from this invention aluminum alloy by the quasicrystal. It has an interim structure of that a quasicrystal is amorphous (amorphous) and the usual crystal, for example, is checked also in aluminum-Cr alloy, aluminum-Mn alloy, an aluminum-Cu-X (X is Fe, Mn, Li, etc.) alloy, etc. It consists of atomic arrangement which has an axis 5 times like 20 face pieces as a feature of the crystal structure, and electron diffraction shows a diffraction pattern symmetrical with 5 times or 10 times. A characteristic peak is presented in an X diffraction. In this invention aluminum alloy, the quasicrystal of an aluminum-Cr-Fe system and an identical or similar quasicrystal are included. And this quasicrystal contributes to the improvement in high temperature strength etc., without being accompanied in particular by the sharp fall of ******.
[0022] The quasicrystal size in this invention aluminum alloy is usually 0.2 micrometer or less, and is 0.05-0.1 micrometer more preferably. When quasicrystal size exceeds 0.2 micrometer, the desired characteristics (processability, a moldability, etc.) are no longer obtained.
[0023] The volume fraction -- usually -- a 0.1 - 20 volume % grade -- it is one to 10 volume % preferably. When a volume fraction is less than 0.1 volume %, desired intensity, heat resistance, etc. cannot be obtained. In exceeding 20 volume %, the sliding surface of a matrix decreases relatively and processability, a moldability, etc. fall. It can ask for a volume fraction, for example from a microphotograph.
[0024] As for this invention aluminum alloy, the Charpy impact value of more than 2 J/cm^2 is more than 2.3 J/cm^2 preferably. It can be said that it excels in ******, a moldability, etc., so that a Charpy impact value is high. The measuring method of the Charpy impact value in this invention is shown in the after-mentioned example.
[0025] From a viewpoint of for example making the quasicrystal of desired quantity form, the rapid solidification method is suitable, for example, an atomizing method, a quenching roll method, a rotating-disc method, the spraying drum method, etc. are mentioned, and the manufacturing method of this invention aluminum alloy has especially a preferred atomizing method.
[0026] A cooling rate -- usually -- 10^{2} - a 10^{6}**/sec grade -- what is necessary is to just be preferably referred to as 10^{3} - 10^{5}**/sec When a cooling rate is less than 10^{2}**/sec, a desired quasicrystal is not not only obtained, but a big and rough intermetallic compound crystallizes and there is a possibility that ****** and a moldability may fall remarkably. When exceeding 10^{6}**/sec, movement of the rearrangement [increase / too much / the abundance ratio of a quasicrystal] within a matrix is barred, and there is a possibility that ****** and a moldability may fall too.
[0027] As for powdered particle size distribution, it is desirable for an about 5-45-micrometer thing to usually adjust to 80% of the weight or more of the whole powder. If the powder over

45 micrometers increases in number too much, it will become difficult to obtain a desired cooling rate. If there is too much powder below 5 micrometers, oxides (the amount of oxygen) will increase in number, and the fall of ******, poor molding, etc. will be caused.
[0028] What is necessary is just to determine spraying intermediation and spraying atmosphere suitably according to the use of a final product, etc., and they may be any, such as the atmosphere, inactive gas, or these mixed gas. For example, what is necessary is just to introduce inactive gas if needed, when restricting the amount of oxygen.
[0029] The obtained powder performs a classification if needed. The classification method should just follow the classification method of the publicly known powder by a sieve etc. A big and rough powder particle has a high possibility that that in which the quasicrystal is not formed, for example, the thing which is generating big and rough crystallized material, etc. are contained, and it is preferred to remove these powder particles beforehand by a classification. 150 micrometers or less of things of 45 micrometers or less should just usually be preferably used for a powdered particle size as this invention aluminum alloy. Powdered shape in particular may not be restricted, for example, may be which shape, such as the shape of a real ball, the shape of a spheroid, unfixed shape, tear-drop, and flat shape.
[0030] When carrying out solidification shaping of the powder of this invention aluminum alloy further, each publicly known forming process currently enforced industrially can be adopted. For example, what is necessary is to perform preforming by CIP or cold pressing if needed, to extrude between heat after that, and just to fabricate and sinter by powder forging between heat, a hotpress, HIP, etc. Also in these, the method by powder forging between heat is preferred on industrial production.
[0031] Usually, it is easy to produce the anisotropy of an extrusion direction and a direction vertical to it, and about 10 to 20% of difference may produce among both the extruded material obtained by extrusion between heat, etc. in intensity, ******, etc. On the other hand, even if there is this anisotropy in the case of powder forging between heat, the above-mentioned difference is usually 5% or less. Since it is a near net shape to an extruded material being usually just over or below 70% also about the yield in the case of powder forging between heat, it is usually not less than 98%. The billet for extrusion has many large-sized things, and the heating takes a long time to it in many cases. In that respect, since it is a near net shape, a necessary minimum size may be sufficient, in the case of powder forging between heat, there is also little time which heating takes, and it ends.
[0032] Since they have good ductility over a wide temperature requirement, even if this invention aluminum alloys are complicated-shaped parts, their powder forging process between heat with cooking time short also in the meaning of preventing generation of a big and rough compound from a quasicrystal it being able to manufacture by powder forging between heat is preferred. On the other hand, in the case of the simple products (for example, rod form, pipe shape, etc.) of shape, the extrusion may be more advantageous in the equipment surface of a device, a metallic mold, etc. Therefore, what is necessary is just to choose a forming process suitably in this invention aluminum alloy according to the shape of a final product, etc.
[0033] Although hot forming in the inside of the atmosphere is possible for this invention aluminum alloy, as long as the amount of oxygen is a problem, it may perform processing in a degassing process and inactive gas etc. if needed by a use etc. Since this invention aluminum alloy also has the deformability in a room temperature, it can also carry out complicated processing of reform of distortion etc., a caulking, machining, etc., etc. easily with cold forging, a press, etc.
[0034]
[Effect of the Invention] The quasicrystal phase and crystalline substance intermetallic compound in the alloy structure contribute this invention aluminum alloy mainly to heat-

resistant improvement. Since it is distributing minutely and uniformly to the in-house and especially the quasicrystal phase is stable also in processing or molding temperature, it does not produce big-and-rough-izing or degradation of the characteristic by a phase transformation. There are comparatively few things used as deformation resistance in a matrix, it excels in hot-forming nature and subsequent cold work nature is also good. It excels in the toughness in a room temperature.

[0035] More specifically, this invention aluminum alloy has intensity and ductility outstanding in the wide temperature requirement from ordinary temperature to about 300 ** elevated temperature. It excels also in a moldability, and since the quasicrystal phase produced in the alloy is also stable, it has the advantage that thermomechanical treatment can be carried out with the various characteristics maintained. It is possible in processing of versatility [excel / in the toughness in a room temperature], and the reliability as a material in a various application is high.

[0036] This invention aluminum alloy with such a feature can be broadly used for a structural material, machinery material, a transportation machine member, etc.

[0037]

[Example] Hereafter, an example and a comparative example are shown and the place by which it is characterized [of this invention] is clarified further.

[0038] The molten metal of the presentation shown in the example 1 table 1 was prepared, and it powdered with the atomizing method. The obtained powder was classified in -45 micrometer and it preformed between the colds to the billet with a 30 mm [in diameter] x height of about 80 mm. Then, it heated at 350°C for 30 minutes, and extruded with the extrusion ratio 10 at the temperature.

[0039] After producing the test piece for tensile test from the obtained extruded rod and holding at each temperature of a room temperature, 200°C, and 300°C for 100 hours, the tensile test was done at the temperature. Those results are shown in Tables 1-3. The Charpy test in a room temperature was done. The Charpy test was done based on JIS Z2242. The section started and used the thing with U notch for the piece of a Charpy test with 1 / 2 width sizes of the JIS No. 3 specimen from the extruded material of the rectangle which are about 7 mm x 11 mm. The result is shown in Table 1.

[0040]cThe marginal upset rate was measured as an index of hot forming/processability. Generally, as this value is large, it excels in deformability. The result is also shown in Table 1. The measuring method of the marginal upset rate started the phi10x15mm test piece from the above-mentioned extruded rod first, prepared it each ten pieces, ****(ed) each test piece between cylindrical metallic molds, changed the upset rate by 70 mm/second in forge speed at 450 **, and searched for the marginal upset rate EhC (%) according to the following formula.

[0041] EhC=(h0-hc) x100/h0 (however, height (15 mm) of the sample before h0:modification, hc: height of the sample after modification)

[0042]

[Table 1]

室温	引張強度	0.2% 耐力	伸び	シャルピー衝撃値	限界据込率	準結晶の存在比	
	MPa	MPa	%	J／cm^2	%	vol%	
1Fe-1Ni-2Cr	358.6	254.1	23.8	24.35	88.0	0	比較例
2Fe-2Ni-3Cr	438.9	326.5	20.3	9.22	79.4	1.9	実施例
3Fe-3Ni	354.5	306.4	14.1	8.36	80.3	0	比較例
3Fe-3Ni-3Cr	439.1	414.9	8.8	4.48	76.8	7.2	実施例
3Fe-3Ni-4.5Cr	483.0	419.8	4.6	2.39	75.5	11.5	実施例
5Fe-5Ni-6Cr	523.8	--	0.1	1.80	59.5	21.0	比較例
3Fe-3Ni-3Cr-0.7Zr	478.8	419.4	10.9	3.97	74.6	6.7	実施例
8Fe-3Ni-3Cr	501.2	488.7	0.4	1.91	62.2	12.3	比較例

[0043]
[Table 2]

200℃	引張強度	0.2% 耐力	伸び
	MPa	MPa	%
1Fe-1Ni-2Cr	219.3	173.3	16.2
2Fe-2Ni-3Cr	275.1	215.2	14.4
3Fe-3Ni	214.7	197.6	12.1
3Fe-3Ni-3Cr	301.3	274.6	6.6
3Fe-3Ni-4.5Cr	338.5	310.0	5.0
5Fe-5Ni-6Cr	458.7	382.6	1.7
3Fe-3Ni-3Cr-0.7Zr	318.9	291.2	8.6
8Fe-3Ni-3Cr	324.0	303.7	3.9

[0044]
[Table 3]

300℃	引張強度	0.2% 耐力	伸び
	MPa	MPa	%
1Fe-1Ni-2Cr	168.0	147.3	10.8
2Fe-2Ni-3Cr	202.4	170.1	20.0
3Fe-3Ni	139.4	124.4	23.6
3Fe-3Ni-3Cr	215.1	188.2	12.4
3Fe-3Ni-4.5Cr	233.3	205.7	8.9
5Fe-5Ni-6Cr	323.4	217.2	4.7
3Fe-3Ni-3Cr-0.7Zr	234.5	218.8	10.7
8Fe-3Ni-3Cr	291.6	262.1	4.5

[0045] Hot forging (forging temperature: 350°C, retention time:15 minutes) was performed for what was preformed to phi59x50mm(H) by cold pressing within the metallic mold of phi 61 using the end of precursor powder it was obtained in example 2 Example 1. Each specimen was produced from the acquired forge object, and the same examination as Example 1 was done. Those results are shown in Tables 4-6.
[0046]
[Table 4]

室温	引張強度	0.2% 耐力	伸 び	ｼｬﾙﾋﾟｰ衝撃値	限界据込率	晶出物の体積比	
	MPa	MPa	%	J／cm²	%	vol%	
1Fe-1Ni-2Cr	364.9	262.2	24.1	26.44	88.5	0	比較例
2Fe-2Ni-3Cr	444.7	336.0	21.4	9.59	80.8	2.0	実施例
3Fe-3Ni	365.6	312.5	14.8	8.82	81.4	0	比較例
3Fe-3Ni-3Cr	442.2	423.6	9.3	4.68	77.1	7.2	実施例
3Fe-3Ni-4.5Cr	495.8	433.4	4.9	2.40	76.1	12.2	実施例
5Fe-5Ni-6Cr	541.9	--	0.1	1.76	57.7	22.5	比較例
3Fe-3Ni-3Cr-0.7Zr	483.5	423.4	11.8	4.11	75.6	6.9	実施例
8Fe-3Ni-3Cr	512.6	493.0	0.3	1.82	61.8	13.4	比較例

[0047]
[Table 5]

200℃	引張強度	0.2% 耐力	伸 び
	MPa	MPa	%
1Fe-1Ni-2Cr	220.9	174.1	16.6
2Fe-2Ni-3Cr	288.3	224.4	15.0
3Fe-3Ni	225.5	199.7	12.9
3Fe-3Ni-3Cr	321.6	283.3	6.8
3Fe-3Ni-4.5Cr	343.5	314.1	5.5
5Fe-5Ni-6Cr	458.9	383.5	2.0
3Fe-3Ni-3Cr-0.7Zr	324.8	295.9	8.8
8Fe-3Ni-3Cr	340.5	328.7	3.6

[0048]
[Table 6]

300℃	引張強度	0.2% 耐力	伸 び
	MPa	MPa	%
1Fe-1Ni-2Cr	172.6	149.1	11.3
2Fe-2Ni-3Cr	209.8	174.5	20.3
3Fe-3Ni	114.2	128.8	24.4
3Fe-3Ni-3Cr	221.0	195.2	12.9
3Fe-3Ni-4.5Cr	237.7	211.1	8.9
5Fe-5Ni-6Cr	325.4	274.4	4.6
3Fe-3Ni-3Cr-0.7Zr	240.1	222.6	11.1
8Fe-3Ni-3Cr	299.0	271.2	4.3

[0049] This invention aluminum alloy has a good moldability, and the above result shows intensity, ductility, etc. outstanding in a 300°C temperature requirement from the room temperature being shown, and excelling also in the shock resistance in a room temperature.

CLAIMS

[Claim(s)]

[Claim 1] An aluminum alloy characterized by the following.
It is an alloy which uses aluminum as a base, and they are (1) Fe:2-7 % of the weight, Cr:2-12 % of the weight, and nickel:1-10 % of the weight (however, 7 % of the weight <=Fe+Cr+nickel<=15 % of the weight).
(2) At least a part of alloy structure is a quasicrystal, and (3) Charpy impact values are more than 2 J/cm^2.

[Claim 2] An aluminum alloy characterized by the following.
It is an alloy which uses aluminum as a base, and they are (1) Fe:2-7 % of the weight, Cr:2-12 % of the weight, nickel:1-10 % of the weight, and Zr:0.01-2.5 % of the weight (however, 7 % of the weight ≤Fe+Cr+nickel+Zr≤15 % of the weight).
(2) At least a part of alloy structure is a quasicrystal, and (3) Charpy impact values are more than 2 J/cm^2.

[Claim 3] The aluminum alloy according to claim 1 or 2 whose size of a quasicrystal is 0.2 micrometer or less.

[Claim 4] The aluminum alloy according to claim 1 or 2 whose volume fraction of a quasicrystal is 0.1 to 20 volume %.